

DESCRIPTION

OPTICAL DISPLAY APPARATUS

Insert A1

5 TECHNICAL FIELD

The present invention relates to an optical display apparatus for displaying image information and character information.

10 BACKGROUND ART

15 In recent years, an optical display apparatus for displaying image information and character information has been used in various fields. An example of such an optical display apparatus is an electronic optical display apparatus widely used in a traffic information display board, a direction board or a billboard. Related techniques are disclosed in, for example, Japanese Laid-Open Publication Nos. 6-228921, 7-129108, 7-140912, 8-6513, 8-158322, 8-160894, etc. First, one of the most typical examples of such
20 an optical display apparatus, an optical traffic sign incorporating a fluorescent lamp therein, will be described below with reference to the figures. However, various other conventional structures are known in the art, such as those incorporating an LED or an EL device for producing a
25 self-luminous display, and those using an optical fiber or a light guide plate for guiding light from a light source.

Figure 1A is a side view illustrating a structure of a conventional optical traffic sign, and Figure 1B is a
30 front view illustrating the same. Specifically, reference numeral 156 denotes a sign display board, 157 a ring-shaped fluorescent tube, 158 a sign body, and 159 a sign pole.

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The sign display board 156 includes a semi-transparent resin on which a sign pattern is printed. The sign can be recognized even at night by illuminating the pattern from the inside of the sign with light from the ring-shaped fluorescent tube 157. The sign body 158, supporting the ring-shaped fluorescent tube 157 and the sign display board 156, is installed on a side wall beside a road or on a tunnel ceiling by being supported by the sign pole 159.

However, the above-described conventional structure has the following problems.

First, since the sign pattern is either printed on the semi-transparent resin or is made of a color resin, a large portion of light emitted by the ring-shaped fluorescent tube 157, as a light source, is absorbed by the resin, whereby the display is not sufficiently bright.

Second, since the display section, including the sign display board 156 and the fluorescent tube (light source) 157, is supported by the sign body 158, the portion including the display section is large and heavy. Moreover, since the sign pole 159 supporting the same must also be robust, the overall structure is even larger and heavier.

Third, the structure must be installed so that it substantially projects from the installation surface, i.e., a road side wall or a tunnel ceiling. Therefore, it may be hit for some reasons by a moving object such as a person, a car or a load, thereby damaging the display apparatus body while also damaging the moving object. To avoid such an accident requires a large installation space, which is not

economical.

5 The above-described problems arise not only from the
optical traffic sign incorporating a fluorescent lamp
therein, illustrated in Figures 1A and 1B as a conventional
example, but also from those of a self-luminous type such
as an LED or those using an optical fiber or a light guide
plate for guiding light from the light source. Moreover,
10 the problems are not limited to the above-described traffic
sign, but are common to a general class of optical display
apparatuses where a pattern to be displayed is illuminated
with light from a light source.

15 Those using a hologram are possible alternatives
which may solve the above-described problems.

20 First, a principle of producing a hologram based on
a commonly-employed conventional technique and a principle
of displaying (reconstructing) image information using such
a conventional hologram will be described below.

Figure 2A is a diagram schematically illustrating
a typically-employed principle of producing a hologram.

25 In particular, an object O is illuminated with
object illumination light IL emitted from a laser light
source, thereby forming object light OL having information
relating to the shape, etc., of the object O, and making the
object light OL be incident upon a hologram dry plate H1.
30 At the same time, reference light RL1, formed by splitting
light emitted from the same laser light source as the object
illumination light IL by means of a beam splitter, or the
like, is directed to be incident upon the hologram dry

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plate H1 from an inclined direction. Thus, interference fringes between the object light OL and the reference light RL1 are recorded on the hologram dry plate H1. The hologram dry plate H1 on which such interference fringes (having information of the object O) are recorded will hereinafter be referred to also as the "hologram plate H1".

Figure 2B is a diagram schematically illustrating a principle of reconstructing the hologram plate H1 which is provided according to Figure 2A.

In particular, the reconstruction illumination light RI1, which is light from the same laser light source as that used for producing the hologram plate H1, is directed to propagate through the same path as that for the reference light RL1 (see Figure 2A) so as to irradiate the hologram plate H1. Thus, light (reconstruction light) R1, having information of the object recorded on the hologram plate H1, is reconstructed, so that a reconstructed image I1 is observed at a position where the object was originally located.

The above-described method, however, requires the use of a laser light source as a light source when producing and reconstructing the hologram plate H1, and thus has such problems that the cost cannot be reduced and the handling thereof is complicated.

On the other hand, in a reflection-type hologram to be described below, a hologram image can be reconstructed using white light.

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To produce a reflection-type hologram, the hologram plate H1 is first produced by the method as illustrated in Figure 2A, and then irradiated with reconstruction illumination light (laser light) RI21, as illustrated in Figure 3A, in a direction opposite to that of the reconstruction illumination light RI1 illustrated in Figure 2B. Thus, reconstruction light R21, directed from the hologram plate H1 to the position where the object was located, is reconstructed, thereby reconstructing a real image (reconstructed image) I21 of the object at a position where the object was located. Then, a new hologram dry plate H2 is placed at a position spaced apart from the reconstructed image I21 of the object by a distance Z_0 , as illustrated in Figure 3B, and reference light RL2 is directed to be incident upon the hologram dry plate H2 from an inclined direction opposite from the hologram plate H1. The reference light RL2 is formed by splitting light emitted from the same laser light source as the reconstruction illumination light RI21 by means of a beam splitter, or the like. Thus, interference fringes between the reconstruction illumination light RI21 and the reference light RL2 are recorded on the hologram dry plate H2. The hologram dry plate H2 on which such interference fringes (having information of the object) are recorded as a reflection-type hologram will hereinafter be referred to also as the "reflection-type hologram plate H2".

Figure 3C is a diagram schematically illustrating a principle of reconstructing the reflection-type hologram plate H2 formed as described above.

In particular, the reflection-type hologram plate H2 is irradiated with reconstruction illumination

light RI22 (white light from a point light source spaced apart from the reflection-type hologram plate H2 by a certain distance) which propagates in a direction diametrically opposite to that of the reference light RL2 illustrated in Figure 3B. Thus, reconstruction light R22 having information of the object recorded on the reflection-type hologram plate H2 is reconstructed so as to form a reconstructed image I22 at a position where the object was originally located.

In a reflection-type hologram, a wavelength selectivity (color selectivity) in the optical diffraction characteristic (the diffraction efficiency) is high. Therefore, the image I22 is reconstructed by light having a wavelength close to that of the laser light used for producing the hologram. Thus, a color image can also be reconstructed by superposition. However, a clear reconstructed image cannot be obtained when the distance z_0 between the position of the reflection-type hologram plate H2 and a position where the reconstructed image I22 is displayed is large.

The reason why a reconstructed image of the reflection-type hologram is blurred will further be described with reference to Figures 3D and 3E.

The reconstruction illumination light RI22 directed toward the reflection-type hologram is white light. Therefore, wavelengths other than a wavelength λ_0 of the laser light used to produce the hologram are also contained in the reconstruction illumination light RI22. A reflection-type hologram has a high wavelength selectivity, as shown in a graph of Figure 3E illustrating the wavelength

dependency of the diffraction efficiency, whereby substantially none of light having a wavelength far away from the wavelength (center wavelength) λ_0 of the laser light used to produce the hologram is diffracted. Therefore, only light having a wavelength close to the center wavelength λ_0 is diffracted, thereby reconstructing the image I22. In practice, however, light having a wavelength which is close to, but different from, the center wavelength λ_0 , as represented by λ_1 and λ_2 in Figures 3D and 3E, is also contained in the reconstructed light R22, thereby also forming and superimposing reconstructed images from such light on the intended reconstructed image from the light having the center wavelength λ_0 . By this effect, the reconstructed image I22 is blurred when the distance z_0 to the position where the image I22 is formed is set to be large. That is, with a reflection-type hologram, a clear reconstructed image I22 cannot be viewed when it is viewed from a distance greater than the distance z_0 set when producing the hologram. This can be a very critical disadvantage in an application, such as an optical information apparatus, e.g., a traffic sign, which aims to clearly transfer prescribed information.

As described above, the commonly-employed conventional hologram and the reflection-type hologram using the same have significant problems to be solved, in terms of the cost, the accurate display/transfer of information, etc., before they can be used in an optical display apparatus such as a traffic sign, for example.

A hologram display method different from those described above is what is known as a rainbow hologram.

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5 In particular, the rainbow hologram plate H3 is irradiated with reconstruction illumination light RI32 (white light from a point light source spaced apart from the rainbow hologram plate H3 by a certain distance) which propagates in a direction diametrically opposite to that of the reference light RL3 illustrated in Figure 4B. Thus, reconstruction light R32 having information of the object recorded on the rainbow hologram plate H3 is reconstructed and directed toward the position where the slit was located during the hologram production, so as to form a reconstructed image I32 at a position where the object was originally located.

15 With a rainbow hologram formed as described above, a clearer reconstructed image is observed as compared to that observed by a reflection-type hologram. The reason for this will be described with reference to Figures 4D and 4E.

20 The reconstruction illumination light RI32 directed toward the rainbow hologram is white light. Therefore, wavelengths other than a wavelength λ_0 of the laser light used to produce the hologram are also contained in the reconstruction illumination light RI32. However, a rainbow hologram, which is a transmission-type hologram, has a low wavelength selectivity, as shown in a graph of Figure 4E illustrating the wavelength dependency of the diffraction efficiency, whereby a relatively wide range of wavelengths are diffracted to emit the reconstruction light R32, thereby reconstructing the images I32 respectively corresponding to different wavelengths of light.

30 However, since a slit is used when producing the rainbow hologram, the reconstructed images formed by the different wavelengths of light are formed at respectively different

positions (i.e., spatially separated from one another). For example, reconstructed images formed by light having wavelengths which are different from the center wavelength λ_0 , as represented by λ_1 and λ_2 in Figures 4D and 4E, are formed concurrently at positions different from that of the reconstructed image formed by light having the center wavelength λ_0 , but are not spatially superimposed on the intended reconstructed image formed by the light having the center wavelength λ_0 . Therefore, with the rainbow hologram, the reconstructed image I32 is relatively clearly observed, with the color of the image I32 changing as the observation position changes.

The phenomenon that the reconstructed image I32 is observed with different colors depending upon the observation position is where the nomenclature "rainbow hologram" comes from, and various applications have been proposed in the art which take advantage of the phenomenon. However, in view of reconstructing a color image, on the other hand, such a change in the color of the reconstructed image I32 depending upon the observation position presents a disadvantage that a prescribed color image cannot be reconstructed. For example, in the case of the traffic sign as described above, use of a predetermined color also constitutes a part of the information to be transferred. Therefore, the above-described characteristic of the rainbow hologram presents a very critical disadvantage in the application thereof to an optical information apparatus aims to clearly transfer prescribed information.

DISCLOSURE OF THE INVENTION

The present invention has been made in view of the above-described problems existing in the prior art, and has

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an objective of providing a light-weight optical display apparatus which occupies a small space and is capable of reconstructing/displaying image information in a bright and clear manner, by using a hologram technique based on a novel method.

An optical display apparatus provided by one aspect of the present invention includes a hologram device and a light source. The hologram is a reflection-type hologram formed by: light having information of an object which is obtained by using light having passed through a slit; and reference light having an incident optical path different from that of the light having the information of the object, wherein a reconstructed image of the object is displayed by light from the light source. The above-described object is accomplished by such a feature.

In one embodiment, the light having the information of the object is object light which is obtained by irradiating the object with diffused light having passed through the slit. The diffused light may be formed by passing light through a ground glass.

In another embodiment, the light having the information of the object is reconstructed light obtained by reconstructing a transmission-type hologram which is formed by: object light obtained by irradiating the object with diffused light having passed through the slit; and irradiation light having an incident optical path different from that of the object light. The diffused light may be formed by passing light through a ground glass.

The hologram is a reflection-type hologram formed by: light having information of an object which is obtained by using diffused light diffusing in one direction; and reference light having an incident optical path different from that of the light having the information of the object, wherein a reconstructed image of the object is displayed by light from the light source. The above-described object is accomplished by such a feature.

In one embodiment, the light having the information of the object is object light which is obtained by irradiating the object with the diffused light.

In another embodiment, the light having the information of the object is reconstructed light obtained by reconstructing a transmission-type hologram which is formed by: object light obtained by irradiating the object with the diffused light; and irradiation light having an incident optical path different from that of the object light. The reference light may be provided by superposing a plurality of beams on one another in a direction orthogonal to the direction in which the diffused light diffuses.

In still another embodiment, the light having the information of the object is reconstructed light of a transmission-type hologram which is obtained by passing through the slit which is arranged to be adjacent to the transmission-type hologram on which an image of the object is recorded. The reference light may be provided by superposing a plurality of beams on one another in a direction orthogonal to the direction in which the diffused light diffuses.

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5 The light source in the optical display apparatus of the present invention may be a linear light source; and a length and an installation direction of the linear light source may be set so that a predetermined reconstructed image viewing range is obtained.

10 The light source in the optical display apparatus of the present invention may be a linear light source; and a position where a reconstructed image is formed may be shifted by moving the linear light source out of an incident plane.

15 In some cases, the optical display apparatus of the present invention includes a plurality of the hologram devices, wherein the plurality of hologram devices are reconstructed by one light source.

20 The light source in the optical display apparatus of the present invention may be a linear light source. In some cases, the linear light source is a fluorescent lamp or a combination of a fluorescent lamp and a reflecting plate.

25 The light source in the optical display apparatus of the present invention may be a linear light source including a polygon mirror and a point light source.

30 The light source in the optical display apparatus of the present invention may be a linear light source which is a linear light source comprising a cylindrical mirror and a point light source.

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Moreover, according to the present invention, there may be provided an optical display system having a plurality of display units arranged in a depth direction, wherein each of the plurality of display units is the optical display apparatus of the present invention having the above-described feature.

The image display apparatus may include: a display device selected from an LED, a CRT, a polymer dispersed type liquid crystal panel and an organic EL panel; and a polarization switching device.

Moreover, the polarization switching device may include a ferroelectric liquid crystal panel.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A and 1B are a side view and a front view, respectively, illustrating a structure of a conventional optical traffic sign.

Figure 2A is a diagram schematically illustrating a principle of producing a commonly-employed conventional hologram.

Figure 2B is a diagram schematically illustrating a principle of reconstructing the hologram formed as illustrated in Figure 2A.

Each of Figures 3A and 3B is a diagram schematically illustrating a principle of producing a conventional reflection-type hologram.

Figure 12 is a diagram schematically illustrating the geometrical relationship between the height of a hologram and the observation position.

5 Figure 13 is a graph illustrating the relationship between the size of a reconstructed image and the observation position.

10 Figure 14 is a diagram schematically illustrating a structure of an exposure optical system using a one-dimensional diffuser.

15 Figures 15A and 15B are a side view and a plan view, respectively, illustrating a principle of reconstructing the hologram according to the present invention.

20 Each of Figures 16A and 16B is a diagram illustrating a shape of an opening which can be used in observing a reconstructed image according to the present invention.

Figure 17A is a perspective view illustrating a reconstruction optical system of the optical display apparatus of the present invention.

25 Figures 17B and 17C are diagrams illustrating viewing angle ranges obtained when a fluorescent tube of the same length is provided in a horizontal arrangement and a vertical arrangement, respectively.

30 Figure 18 is a side view illustrating a structure of an optical display apparatus according to Embodiment 2 of the present invention.

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Figure 19 is a diagram schematically illustrating that a viewing distance can be limited.

5 Figure 20 is a plan view illustrating the optical display apparatus of the present invention where the installation position of a linear light source (fluorescent lamp) is spaced apart from the incident plane (when it is provided in an offset arrangement)

10 Figure 21A is a diagram illustrating three exposure pattern masks respectively corresponding to the three primary colors.

15 Figure 21B is a diagram illustrating a reconstructed image obtained by superposing the produced three primary color holograms on another.

20 Figure 21C is a diagram illustrating the produced holograms being layered on a single substrate.

25 Figure 22 is a graph illustrating the relationship between the change in color at the center of a reconstructed image and the reference light angle.

30 Figure 23 is a graph illustrating the relationship between the color distribution in the reconstructed image and the reference light angle.

35 Figure 24 is a graph illustrating the relationship between the color distribution in the reconstructed image and the observation position.

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Figure 61 is a side view illustrating a structure of an optical display apparatus in which a plurality of display units are arranged in a depth direction of an image for displaying a single large pattern.

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Each of Figures 62A to 62C is a diagram illustrating an optical system for producing a hologram screen of each display unit included in the optical display apparatus of Figure 61.

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Figure 63A is a diagram illustrating a pattern to be displayed by the optical display apparatus of Figure 61.

Figure 63B is a diagram illustrating elementary patterns which are recorded on the respective display units in the optical display apparatus of Figure 61.

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Figure 63C is a diagram illustrating a reconstructed image displayed by the optical display apparatus illustrated in Figure 61.

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BEST MODE FOR CARRYING OUT THE INVENTION

Before describing specific embodiments of the present invention, the principle of a hologram proposed by the present inventors for realizing an optical display apparatus of the present invention will be described.

25

To produce a hologram according to the present invention, the hologram plate H1 is first produced by the conventional method as illustrated in Figure 2A, which is then irradiated with reconstruction illumination light (laser light) RI41, as illustrated in Figure 2B, in a direction opposite to that of the reconstruction

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illumination light RI1 illustrated in Figure 2B and through a slit having a width of Δ , as illustrated in Figure 5A. Thus, reconstruction light R41, directed from the hologram plate H1 to the position where the object was located, is reconstructed, thereby reconstructing a real image (reconstructed image) I41 of the object at a position where the object was located. Then, a hologram dry plate H4 is placed at a position spaced apart from the reconstructed image I41 of the object by a distance Z0, as illustrated in Figure 5B, and reference light RL4 is directed to be incident upon the hologram dry plate H4 from an inclined direction opposite from the hologram plate H1. The reference light RL4 is formed by splitting light emitted from the same laser light source as the reconstruction illumination light RI41 by means of a beam splitter, or the like. Thus, interference fringes between the reconstruction illumination light RI41 and the reference light RL4 are recorded on the hologram dry plate H4. The hologram dry plate H4 on which such interference fringes (having information of the object) are recorded as a reflection-type hologram will hereinafter be referred to also as the "reflection-type hologram plate H4".

Figure 5C is a diagram schematically illustrating a principle of reconstructing the rainbow hologram plate H4 formed as described above.

In particular, the hologram plate H4 is irradiated with reconstruction illumination light (white light) RI42 which propagates in a direction diametrically opposite to that of the reference light RL4 illustrated in Figure 5B. Thus, reconstruction light R42 having information of the object recorded on the hologram plate H4 is reconstructed

hologram, the reconstructed images formed by the different wavelengths of light are formed at respectively different positions (i.e., spatially separated from one another). For example, reconstructed images formed by light having wavelengths which are different from the center wavelength λ_0 , as represented by λ_1 and λ_2 in Figures 6A and 6B, are formed concurrently at positions different from that of the reconstructed image formed by light having the center wavelength λ_0 , but are not spatially superimposed on the intended reconstructed image formed by the light having the center wavelength λ_0 . Therefore, with the hologram of the present invention, although the color of the reconstructed image I42 slightly changes as the observation position changes, the reconstructed image I42 of each color is clearly observed.

The hologram of the present invention is of a reflection-type, and thus has a high wavelength selectivity in the diffraction efficiency, whereby light having a wavelength other than those closer to the center wavelength λ_0 is not diffracted. Therefore, where white light from a point light source spaced apart from the rainbow hologram plate H4 by a certain distance is used as the reconstruction illumination light, when the observation position changes substantially (i.e., when the observer moves substantially), the diffraction efficiency of the hologram for the wavelength which forms an image which can be observed from the observation position becomes zero, whereby no reconstructed image is observed. In other words, the viewing range for the reconstructed image I42 is extremely narrowed when the hologram of the present invention is reconstructed by collimated light RI42A from a point light source.

However, when the reconstruction illumination light RI42 to be incident upon the hologram plate H4 is not collimated light but is a group of light beams having respective incident angles, as illustrated in Figure 7A, the reconstructed images I42 are reconstructed at spatially different positions by beams of reconstructed light R42 having most suitable wavelengths for the respective incident angles. Such an incident condition can be realized by using a linear light source LL rather than a point light source. In particular, when the linear light source LL such as a fluorescent lamp is used as the light source LL of the reconstruction illumination light RI42 for the hologram of the present invention, as illustrated in Figure 7B, it is possible to intentionally provide a certain angle range to the incident angle of the reconstruction illumination light RI42 for the hologram plate H4, thereby widening the viewing range for the reconstructed image I42.

Then, when the observation position for the hologram of the present invention changes, the color of the reconstructed image I42 changes as in the case of the conventional rainbow hologram. However, the rate of such change in the color of the reconstructed image I42 is as small as several % with respect to the color change of a rainbow hologram. For example, where a hologram plate is formed with reference light of an incident angle of 45° , the wavelength changes on the order of 100 nm for a change in the observation position for a rainbow hologram such that the color of the reconstructed image changes from blue to red. On the contrary, for the hologram of the present invention, the wavelength of the reconstructed image I42 changes by about 6 nm for a similar change in the observation position, whereby substantially no color change is recognized.

When the structure of the hologram of the present invention as described above is applied to a conventional rainbow hologram, reconstructed images of seven colors overlap one another, thereby whitening the overall image.

5 This is because the conventional rainbow hologram is a transmission-type hologram, whereas the hologram of the present invention is of a reflection type and thus has a high wavelength dependency of the diffraction efficiency.

10 Thus, the principle of forming a hologram of the present invention takes advantage of the characteristic of a reflection-type hologram of "a high wavelength dependency of the diffraction efficiency and thus a narrow viewing range for the reconstructed image", which was considered as a
15 disadvantage of the conventional reflection-type hologram, and forms a hologram plate by recording, as a reflection-type hologram, an image reconstructed by laser light which has passed through a slit. When a reconstructed image is obtained by using a hologram plate formed as described above,
20 it is possible to obtain characteristics which were not obtained by various conventional hologram forming principles, e.g.: the image is not substantially blurred even when the observation position is shifted; and the wavelength selectivity is high so that it is possible to
25 obtain a color reconstructed image by superimposing reconstructed images on one another.

Hereinafter, various embodiments of optical display apparatuses according to the present invention which are
30 provided by using the hologram method of the present invention which is based on the above-described principle.

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(Embodiment 1)

Figure 8 is a side view illustrating a structure of an optical display apparatus according to Embodiment 1 of the present invention, and Figure 9 is a plan view of the optical display apparatus. In this embodiment, the optical display apparatus of the present invention is used as a traffic sign in a tunnel.

In Figure 8, reference numeral 1 denotes an optical display apparatus of the present embodiment; 2 a hologram; 3 a fluorescent lamp as a linear light source; 4 fluorescent lamp fittings, and 5 a shield plate. The optical display apparatus 1 is provided on a ceiling plane 7 of a tunnel 6.

A portion of illumination light 8 emitted from the fluorescent lamp 3 is incident upon the hologram 2, and is diffracted by the hologram 2 so as to become reconstructed light 9, thus forming a reconstructed image 11 on a virtual display plane 10. Then, the reconstructed image 11 as viewed from the front side thereof is viewed from a car running through the tunnel 6 as if it were hung at a position downwardly spaced apart from the ceiling plane 7 of the tunnel 6. However, this is only a display (the reconstructed image 11) on the virtual display plane 10, and there is no object actually existing at the position. Therefore, there is no chance for a car collision.

The virtual display plane 10 is a plane or a curved surface which is virtually provided in a space. The reflected light from the surface of the hologram 2 can be deflected in a direction toward the road surface (reflected light in this direction is shown in Figure 8) or in a direction toward the ceiling plane 7 (reflected light in

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this direction is not shown in Figure 8), whereby the reflected light will not be directly incident upon the driver's eye. Rather, the reflected light is effectively used as illumination light for illuminating the road surface or the ceiling plane.

Moreover, a portion of the illumination light 8 from the fluorescent lamp 3 is shielded by the shield plate 5, whereby it will not be directly incident upon the driver's eye. Other portions of the illumination light 8 directed directly toward the road surface or the ceiling plane can also be effectively used as illumination light for illuminating the road surface or the ceiling plane.

The light source section including the fluorescent lamp 3 and the fluorescent lamp fittings 4 may be provided by using common lamp fittings as those used in houses or offices, but it is preferred to make it waterproof so that water does not get into it during a tunnel clean-up. For example, the light source section can be provided by embedding the fluorescent lamp 3 and the fluorescent lamp fittings 4 into the ceiling plane 7 of the tunnel 6, and covering them with a transparent cover.

Next, a principle by which the hologram 2 forms the reconstructed image 11 on the virtual display plane 10 will be described in association with a method for producing the same.

First, a method for producing the hologram 2 will be briefly described with reference to Figure 10.

incident plane 15 which is uniquely defined as a plane vertical to the longitudinal direction of the slit 12. Herein, the reference light 16 is directed to be incident at an angle of 15° from the reverse side of the hologram dry plate 17 to form a reflection hologram. Although it is not necessarily required that the reference light 16 is incident upon the incident plane 15, an arrangement where the reference light 16 is incident upon the incident plane 15 is depicted herein as a more preferred embodiment.

Thus, the object light 14 and the reference light 16 form interference fringes, and the interference fringes are recorded on the hologram dry plate 17. A silver salt, a dichromate gelatin, a photopolymerizable photopolymer, or the like, is typically used as a material of the hologram dry plate 17. For example, a dry-film type photopolymerizable photopolymer having a thickness of about 20 μm is attached to a glass substrate so as to provide the hologram dry plate 17.

Next, the method for producing the hologram 2 will be described in greater detail.

Figures 11A and 11B are a side view and a plan view, respectively, of the optical system for producing a hologram illustrated in Figure 10. Reference numeral 18 denotes a ground glass, 19 laser light, and 20 diffused light.

As illustrated in Figure 11A, the laser light 19 is incident upon the ground glass 18 so as to be the diffused light 20 and then incident upon the slit 12. The slit 12 has a narrow width as viewed from a side thereof, and transmits only a portion of the diffused light 20.

Therefore, light having passed through the slit 12 as viewed from the side appears as spread light coming from a single point. This light reads the information of the pattern mask 13, and irradiates the hologram dry plate 17 as the object light 14. This can be considered as projection of the pattern mask 13 onto the hologram dry plate 17. The object light 14 including the information of the object forms interference fringes with the reference light 16 incident upon the reverse side of the hologram dry plate 17, and the interference fringes are recorded on the hologram dry plate 17.

At this time, the "shadow" of the pattern mask 13 projected onto the hologram dry plate 17 has been enlarged. In view of the rate of projection magnification, the pattern mask 13 is produced while being shrunk in one direction. Although the rate of magnification varies depending upon the setting of the optical system, it normally is about 1.2 to about 2.

More specifically, assuming the original height of the pattern mask 13 to be H_m , and the height of the image actually viewed from the observation position OP to be H_i , the rate of magnification is expressed as follows based on the geometric relationship shown in Figure 12:

$$H_i = H_m(1 - z_0/L') / (1 - z_0/L).$$

Herein, z_0 denotes the distance from the hologram dry plate 17 to the image (the pattern mask 13), L denotes the distance from the hologram dry plate 17 to the slit 12 during the hologram production, and L' denotes the distance from the hologram dry plate 17 to the observation position OP. As can be seen from this, the rate of magnification is 1 when $L=L'$; i.e., there is no enlargement/shrinkage effect

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when the image is observed from the position where the slit 12 was located. On the other hand, an enlargement/shrinkage effect is provided when the distance L' changes, i.e., when the image is observed from a wide area away from the position where the slit 12 was located.

This relationship is illustrated in Figure 13 as the relationship between the normalized observation distance (L'/L) and the normalized image height (H_i/H_m), using L/z_0 as a parameter. This shows that the value L/z_0 may be increased in order to reduce the change in the rate of magnification experienced when the image is viewed from a wide area. The rate of magnification can be suppressed to be 1.1 or less (i.e., a change in shape of 10% or less) even when the image is viewed from a wide area, preferably by setting L/z_0 to be 10 or more.

More preferably, if the value L/z_0 is selected to be substantially infinite, the change in the rate of magnification would be substantially eliminated. Back to the definition, selecting the value L/z_0 to be substantially infinite means that, excluding the case where $z_0=0$, the line extending from the slit 12 to the hologram dry plate 17 has no gradient. Therefore, the slit 12 and the ground glass 18 may be replaced with a one-dimensional diffuser 1001 which has a light diffusing effect only in the width direction of the hologram dry plate 17 with no light diffusing effect in the height direction of the hologram dry plate 17, as illustrated in Figure 14. There are a number of examples for such a diffuser 1001, including those using a diffraction grating, or those which are holographically produced, or a lenticular lens sheet having an array of cylindrical lenses may alternatively be used.

Now, the method for producing a hologram using the slit 12 and the ground glass 18 will be further described.

As illustrated in the plan view of Figure 11B, the slit 12 has a large width as viewed from the above, and transmits the diffused light 20 coming from the ground glass 18 over a wide range. In Figure 11B, diffused light having passed through the central portion of the slit 12 is indicated by a solid line, while diffused light having passed through an end portion of the slit 12 is indicated by a broken line. Information of the pattern mask 13 obtained when viewed from the front side thereof is projected onto the hologram dry plate 17 by the diffused light indicated by the solid line, whereas information of the pattern mask 13 obtained when viewed from a slightly inclined direction through the end portion of the slit 12 is projected onto the hologram dry plate 17 by the diffused light indicated by the broken line. The object light 14 including such information forms interference fringes with the reference light 16 incident upon the reverse side of the hologram dry plate 17, and the interference fringes are recorded on the hologram dry plate 17. This is the principle of how reconstructed images of the pattern mask 13 as viewed from different angles are formed on the respective eyes of the observer when the hologram is reconstructed.

Although side views and plan views have been separately described in the above for simplicity, it is understood that the interference fringes are simultaneously recorded in an actual hologram producing process.

Now, a principle of reconstructing the hologram of the present invention will be described.

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Therefore, the present inventors continued to study the positional relationship between the light source and the hologram, and the interaction between the illumination light and the hologram, and conducted a more detailed observation of the reconstructed image, thereby discovering a unique practical advantage which is extremely important to solving the above-described problems and providing the optical display apparatus 1 of the present invention.

Figures 16A and 16B illustrate two characteristic shapes for the opening 22 used during the above-described observation of the reconstructed image.

As a result of the observation, while the reconstructed image of the hologram 2 was blurred when the width of the opening 22 was widened in the horizontal direction as illustrated in Figure 16A, while the reconstructed image of the hologram 2 was not blurred when the length of the opening 22 was extended in the vertical direction as illustrated in Figure 16B. Moreover, the viewing range in the vertical direction was increased as the length of the opening 22 was extended, with the color of the reconstructed image being unchanged within the viewing range. That is, the observer always observes an image of the same color which is not blurred within the viewing range. This is a significant advantage provided by providing the hologram 2 with a reflection-type hologram.

When the opening 22 which is elongated in the vertical direction is used, the entire reconstructed image can be observed even when the observer moves from the position where the reconstructed image 26 of the slit 12 is formed toward the hologram 2 or away from the hologram 2.

hologram 2 changes, whereby the reconstructed image can be seen sufficiently before the optical display apparatus 1.

5 While the reference light 16 is directed to be incident upon the incident plane 15 in the process of producing the hologram, the present invention is not limited thereto. Moreover, while the fluorescent lamp is arranged on the incident plane 15 for reconstructing the image, the present invention is not limited thereto. According to the
10 present invention, the incident direction of the reference light and the arrangement and direction of the linear light source each have some degree of tolerance.

15 Moreover, for the method of producing a hologram using the diffuser 1001, the incident plane can be defined as a plane perpendicular to the direction in which the diffused light is spread. While the reference light is directed to be incident upon the incident plane in the basic arrangement, the present invention is not limited thereto.
20 Moreover, although the fluorescent lamp is arranged on the incident plane for reconstructing the image in the basic arrangement, the present invention is not limited thereto.

(Embodiment 2)

25 While the fluorescent lamp 3, which is a linear light source, is horizontally arranged in Embodiment 1, the installation condition of the fluorescent lamp 3 is not limited in terms of the orientation thereof as long as it is basically placed in a position on the incident plane 15
30 or in the vicinity of such a position.

Figure 17A is a perspective view illustrating a reconstruction optical system of the optical display

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apparatus of the present invention, wherein the system may be arranged in either one of the horizontal and vertical arrangements illustrated, or at any intermediate angle therebetween. However, the viewing angle range in the vertical direction varies depending upon the installation direction.

Figures 17B and 17C are diagrams for comparing the viewing angle ranges obtained when a fluorescent tube of the same length is provided in the horizontal arrangement and the vertical arrangement.

In the case of the horizontal arrangement of Figure 17B, illumination light 28 emitted from the right end of a fluorescent lamp 27 is diffracted by the hologram 2, thereby forming a reconstructed image 29, which is recognized by an observer 30. On the other hand, illumination light 31 emitted from the left end of the fluorescent lamp 27 is diffracted by the hologram 2, thereby forming a reconstructed image 32, which is recognized by an observer 33. The angle formed by the position of the observer 30 and that of the observer 33 with respect to the hologram 2 is the viewing angle range for the horizontal arrangement.

In the case of the vertical arrangement of Figure 17C, illumination light 34 emitted from the lower end of the fluorescent lamp 27, which is indicated by a solid line, is diffracted by the hologram 2, thereby forming a reconstructed image 35, which is recognized by an observer 36. On the other hand, illumination light 37 emitted from the upper end of the fluorescent lamp 27 is diffracted by the hologram 2, thereby forming a reconstructed image 38, which is recognized by an observer 39. The angle formed by the

position of the observer 36 and that of the observer 39 with respect to the hologram 2 is the viewing angle range for the vertical arrangement.

5 A comparison between the horizontal arrangement and the vertical arrangement shows that a larger viewing angle can be obtained with the vertical arrangement. From a different point of view, a shorter fluorescent lamp can be used when employing an arrangement close to the vertical
10 arrangement. Strictly speaking, it is more preferred to arrange the fluorescent lamp to be perpendicular to the optical path for the reconstruction illumination light.

15 Figure 18 is a side view illustrating a structure of an optical display apparatus according to Embodiment 2 of the present invention. Also in this embodiment, the optical display apparatus of the present invention is used as a traffic sign in a tunnel.

20 In Figure 18, reference numeral 40 denotes the optical display apparatus of the present embodiment, 41 a fluorescent lamp, which is a linear light source, 42 fluorescent lamp fittings, and 43 a reflecting plate. The optical display apparatus 40 is provided on the ceiling
25 plane 7 of the tunnel 6.

30 Direct light emitted from the fluorescent lamp 41 and indirect light which has been once reflected by the reflecting plate 43 are synthesized together, thereby forming illumination light 44. The effect of the reflecting plate 43 makes possible an even brighter display. A portion of the illumination light 44 which is incident upon the hologram 2 is diffracted by the hologram 2 to be recon-

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5 structed light 45, thereby forming the reconstructed im-
age 11 on the virtual display plane 10. Then, the recon-
structed image 11 as viewed from the front side thereof is
viewed from a car running through the tunnel 6 as if it were
10 a traffic sign indicating a speed limit hung at a position
downwardly spaced apart from the ceiling plane 7 of the
tunnel 6. However, this is only a display (the recon-
structed image 11) on the virtual display plane 10, and there
is no object actually existing at the position. Therefore,
15 there is no chance for a car collision.

15 The virtual display plane 10 is a plane or a curved
surface which is virtually provided in a space. The re-
flected light from the surface of the hologram 2 can be
deflected in a direction toward the road surface (reflected
light in this direction is shown in Figure 18) or in a
direction toward the ceiling plane 7 (reflected light in
this direction is not shown in Figure 18), whereby the
reflected light will not be directly incident upon the
20 driver's eye. Rather, the reflected light is effectively
used as illumination light for illuminating the road surface
or the ceiling plane.

25 Moreover, a portion of the illumination light 44
from the fluorescent lamp 41 is shielded by the fluorescent
lamp fittings 42 and/or the reflecting plate 43, whereby it
will not be directly incident upon the driver's eye. Other
portions of the illumination light 44 directed directly
toward the road surface or the ceiling plane can also be
30 effectively used as illumination light for illuminating the
road surface or the ceiling plane.

The light source section including the fluorescent lamp 41 and the fluorescent lamp fittings 42 may be provided by using common lamp fittings as those used in houses or offices, but it is preferred to make it waterproof so that water does not get into it during a tunnel clean-up. For example, the light source section can be provided by covering the fluorescent lamp 41 and the fluorescent lamp fittings 42 with a transparent cover.

10 (Embodiment 3)

The viewing range can be intentionally limited by utilizing the above-described characteristic that the viewing angle range is dependent upon the length of the fluorescent lamp and the direction in which the fluorescent lamp is arranged. For example, by appropriately setting the length of the fluorescent lamp and the direction in which the fluorescent lamp is arranged, it is possible to realize an arrangement such that the traffic sign becomes visible at a distance of 100 m before the sign and becomes invisible at a distance of 50 m before the sign, as illustrated in Figure 19.

This arrangement can be practiced with an optical display apparatus of any of the embodiments described in this specification.

(Embodiment 4)

Figure 20 is a plan view illustrating an optical display apparatus of the present invention where the installation position of the fluorescent lamp 46 is spaced apart from the incident plane 15.

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A reconstructed image 48 can be well recognized also in this case though it is associated with a slight change in color and a slight reduction in the viewing angle range. However, the observer 49 needs to observe the image from a position moved from the incident plane 15 in a direction opposite to the direction in which the fluorescent lamp 46 is moved from the incident plane 15, as illustrated in Figure 20. This is because illumination light 47 is incident upon the hologram 2 in an inclined direction, whereby the reconstructed image 48 is formed at a position spaced apart from the incident plane 15. The above-described arrangement can be positively used for display, when it is difficult to install the fluorescent lamp 46 on the incident plane 15 for reasons such as for saving the installation space for the optical display apparatus. It is understood that it is possible to intentionally produce a hologram in view of such a reconstruction arrangement.

This arrangement can be practiced with an optical display apparatus of any of the embodiments described in this specification.

(Embodiment 5)

Only the process for a single pattern mask and the reconstruction of a hologram produced by such a process have been described above. This may suffice for a single color display. However, for producing a color display, a hologram is produced by layering different pattern masks corresponding to the colors to be displayed on one another so as to realize the color display.

Figure 21A illustrates three exposure pattern masks corresponding to the three primary colors. These pattern

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5 masks are used as objects so as to produce single-color holograms of R, G and B, respectively. Figure 21B illustrates a reconstructed image obtained by superposing the three produced holograms on one another. Figure 21C illustrates the produced holograms being layered on a single substrate.

10 The useful characteristic of the hologram described in the embodiments of the present invention, i.e., the characteristic that the color of the reconstructed image does not change within the viewing range even when the vertical opening limit width is widened, holds for various colors. Therefore, the color of the color reconstructed image of the layered hologram does not change within the viewing range (strictly speaking, the reconstructed wavelength slightly changes, but the change in wavelength cannot be perceived by a human eye as a substantial change in color). The change in the reconstructed wavelength at the center of the reconstructed image depends upon the incident angle θ of the reference light which is set when producing the hologram of each color, as illustrated in the wavelength shift ratio with respect to the incident angle θ of the reference light ($\Delta\lambda_R/\Delta\lambda_T$) in Figure 22. In particular, the change in color increases as the incident angle θ of the reference light increases. However, in the case where the incident angle of the reference light $\theta=30^\circ$, for example, the change in color (the change in wavelength) within a viewing angle range of $\pm 2^\circ$, which is required for a sign, is about 4 nm, which cannot be substantially perceived by a human eye. Therefore, for a commonly-employed incident angle of the reference light, $\theta=45^\circ$ or less, the reconstructed image is perceived as having a single color.

The wavelength shift ratio with respect to the incident angle θ of the reference light ($\Delta\lambda_R/\Delta\lambda_T$), as illustrated in Figure 22, denotes the ratio of the amount of wavelength shift $\Delta\lambda_R$ for the arrangement of the present invention, which is a reflection-type hologram, with respect to the amount of wavelength shift $\Delta\lambda_T$ for a transmission-type hologram such as the conventional rainbow hologram.

More strictly, when a color distribution exists in the reconstructed image, and the incident angle θ of the reference light increases, the color distribution increases. This relationship is illustrated in Figure 23 as the relationship between the reference light angle and the reconstructed wavelength width. Herein, H denotes the height of the hologram. Figure 23 shows that by selecting the parameter L/H to be a large value, it is possible to reduce the color distribution to an unrecognizable level within the range of the incident angle of the reference light, $\theta=45^\circ$ or less.

The color distribution in the reconstructed image also changes depending upon the observation position. In particular, the change in color increases as the observation position moves farther away. This relationship is illustrated in Figure 24 as the relationship between the normalized observation position and the reconstructed wavelength width. This shows that by appropriately selecting the parameter L/H , it is possible to reduce the color distribution to an unrecognizable level.

More preferably, if the value L/H could be selected to be substantially infinite, the change in the rate of

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5 magnification would be substantially eliminated. Back to
the definition, selecting the value L/H to be substantially
infinite means that the line extending from the slit to the
hologram has no gradient. Therefore, the slit and the ground
10 glass may be replaced with a one-dimensional diffuser which
has a light diffusing effect only in the width direction
of the hologram with no light diffusing effect in the height
direction of the hologram. There are a number of examples
for such a diffuser, including those using a diffraction
15 grating, or those which are holographically produced. For
example, a lenticular lens sheet having an array of
cylindrical lenses may be used.

15 The arrangement of the exposure optical system to
be used in such a case is as described above with reference
to Figure 14.

20 The arrangement of the present embodiment as de-
scribed above can be practiced with an optical display
apparatus of any of the embodiments described in this
specification.

(Embodiment 6)

25 The hologram 2 of the present invention can be
layered with a flexible substrate which can be bent, rolled,
or folded, as illustrated in Figures 25A to 25C, respec-
tively.

30 While a hologram dry plate is formed by attaching
a dry film type photopolymer to a glass substrate in the
above-described process of producing the hologram 2, the
photopolymer on which a hologram image has been recorded
can be detached from the glass substrate and re-attached

to another substrate after the process. The hologram 2 of the present invention can be bent, rolled or folded, as illustrated in Figures 25A to 25C, respectively, after it is re-attached to another flexible substrate, including but not limited to, a plastic film, paper, cloth, or the like. This allows for compact storage of the display apparatus not being used, and such a display apparatus can easily be carried around.

10 In such a case, it is not necessary to carry around the light source. This is because it is very easy to find a place where a fluorescent lamp is used, and the reconstructed image can easily be obtained by simply unfolding the hologram in the vicinity of a fluorescent lamp which is used in a house, an office, a train station, a train car, an elevator, or the like. Thus, the hologram of the present invention can be effectively used as a poster, a direction board, a billboard, etc., as well as in various other applications. Moreover, regarding the installation, it can be adequately installed simply by attaching it to a wall surface by common means such as a pushpin, a tape, or the like. The embodiment as described above is made possible because according to the present invention, the reconstructed image of the hologram can be displayed with a fluorescent lamp, which is one of the most commonly-employed light sources.

Moreover, the hologram can be provided in the form of a film or a book by superposing a plurality of holograms on one another. In such a case, reconstructed images can be viewed under a fluorescent lamp as by turning over pages of a book, and such a hologram can be effectively used as a trade catalog, a picture book, a map, etc., as well as

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in various other applications.

Moreover, it is possible to reconstruct a continuous image by recording the image on a looped flexible substrate as illustrated in Figure 25D and by moving the same by means of a roll. Alternatively, it can be provided in a wind-up form as illustrated in Figure 25E.

The arrangement of the present embodiment where a hologram is layered on a flexible substrate as described above can be practiced with an optical display apparatus of any of the embodiments described in this specification.

(Embodiment 7)

A laser typically used as an exposure laser includes an argon laser or a krypton laser, each having primary oscillation wavelengths of 488 nm, 514.5 nm and 467.1 nm. Through exposure with the three wavelengths, it is possible to reconstruct and display colors of the wavelengths. However, the following process is generally required to reconstruct and display colors of wavelengths other than the oscillation wavelength of the laser, e.g., to display green at 550 nm, to which a human eye has the highest visibility, or to display yellow in the vicinity of 570 nm.

Where a silver salt is used as the hologram material, the sample is exposed with an argon laser at 514.5 nm, and then immersed in an appropriate solution, so as to widen the interval of the periodic arrangement of the hologram, thereby shifting the reconstructed wavelength to 550 nm or 570 nm. Alternatively, where a dry film type photopolymer is used, the sample is similarly exposed with an argon laser at 514.5 nm, and then the entire surface of the sample is

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irradiated with UV light, after which a color tuning film is layered on the sample, followed by a heat treatment. The movement of a swelling substance from the color tuning film to the photopolymer side widens the interval of the periodic arrangement, thereby shifting the reconstructed wavelength to 550 nm or 570 nm. In any case, such a method is not preferable in view of improving the production efficiency because it is necessary to perform an additional process after laser exposure.

10

On the contrary, for the hologram of the optical display apparatus of the present invention, it is possible to shift the reconstructed color by setting the reference light and the object light so that they are incident upon the hologram dry plate at an appropriate angle during the laser exposure, without subsequently performing the additional process.

Figure 26 illustrates a side view of an optical system for producing a hologram which is reconstructed and displayed with a color having a wavelength other than the laser oscillation wavelength. Unlike the optical system illustrated in Figure 15A, a hologram dry plate 50 is inclined by an angle θ_{obj} with respect to the optical axis of the object light. A pattern mask 51, which is an object, is similarly inclined by the angle θ_{obj} . The pattern mask 51 is produced while being further shrunk in one direction as compared to the above-described pattern mask 13. Strictly speaking, the pattern mask 51 is not produced with a uniform shrinkage rate, but with a shrinkage rate which continuously varies for various positions of the pattern mask 51. On the other hand, reference light 52 is arranged to be incident upon the reverse side of the hologram dry

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plate 50 at an angle θ_{ref} .

Where the exposure is performed with laser light at a wavelength $\lambda=514.5$ nm, for example, using such a producing optical system, a reconstructed image of bright green at a wavelength $\lambda_E=550$ nm can be observed over the front surface of the hologram dry plate during reconstruction by setting the object light angle θ_{obj} and the reference light angle θ_{ref} to be -25.3° and 42.1° , respectively. Then, the incident angle of the illumination light having a wavelength of 550 nm is 15° .

Where the exposure is similarly performed with laser light at a wavelength $\lambda=514.5$ nm, a reconstructed image of bright yellow at a wavelength $\lambda_E=570$ nm can be observed over the front surface of the hologram dry plate during reconstruction by setting the object light angle θ_{obj} and the reference light angle θ_{ref} to be -33.1° and 51.2° , respectively. Then, the incident angle of the illumination light having a wavelength of 570 nm is also 15° .

The above-described angle can be determined from the following relation:

$$\begin{aligned} \theta_{\text{RE}} &= \sin^{-1}[n \cdot \sin\{(\theta_0 + \theta_R)/2 + \pi - \phi\}]; \text{ and} \\ \theta_{\text{OE}} &= \sin^{-1}[n \cdot \sin\{(\theta_0 + \theta_R)/2 + \phi\}]. \end{aligned}$$

Herein, θ_{RE} and θ_{OE} are the incident angles of the illumination light and the reconstructed light, respectively, for the wavelength to be displayed. π denotes the ratio of the circumference of a circle to its diameter, and n denotes the average refractive index of the hologram material. Herein, the calculation was conducted with $n=1.52$. Moreover, θ_R , θ_0 and ϕ are parameters which are respectively expressed as follows:

$$\begin{aligned}\theta_0 &= \sin^{-1}(\sin\theta_{obj}/n); \\ \theta_R &= \sin^{-1}(\sin\theta_{ref}/n) - \pi; \text{ and} \\ \phi &= \sin^{-1}[\lambda \sin\{(\theta_0 - \theta_R)/2\} / \lambda E].\end{aligned}$$

5 Thus, it is possible to display any intermediate
color by using a hologram which has been produced so as to
exhibit a desired reconstructed wavelength in combination
with a light source having a continuous emission
distribution, e.g., a white fluorescent lamp. Moreover, it
10 is possible to display a bright reconstructed image with
a high light efficiency by combining it with a light source
having three emission peaks, corresponding to the three
colors of R, G and B, e.g., a three-wavelength fluorescent
lamp.

15 The arrangement of the above-described embodiment
as described above can be practiced with an optical display
apparatus of any of the embodiments described in this
specification.

20 (Embodiment 8)

As described above in Embodiment 5 of the present
invention, as the field of view of the observer is moved
in the vertical direction, the reconstructed wavelength
25 slightly changes. Assuming that the object light is
incident upon the hologram from the front side thereof while
producing the hologram, the degree of the change in color
depends upon the set incident angle θ of the reference light,
and the change in color increases as θ increases. For
30 example, when θ exceeds 45° , a change in the reconstructed
wavelength of 6 nm or more occurs in the center of the
reconstructed image within the viewing angle range of $\pm 2^\circ$,
which is required for a sign, whereby even a human eye

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recognizes a slight change in color in the portion where the change in hue is substantial. Moreover, the color distribution within the image becomes more significant.

5 While a method for producing a hologram by optimally selecting the parameter L/H to suppress such a change has already been described above in Embodiment 5, there exists a hologram setting angle, for the hologram of the optical display apparatus of the present invention, with which it is possible to minimize the change in color after production. The setting angle is an angle which is substantially 1/2 of the angle between the illumination light and the object light; and more exactly an angle which satisfies the following relation:

15
$$\theta_{ac} = \sin^{-1}[n \cdot \sin\{(\theta_0 + \theta_R + \pi)/2\}].$$

For example, when the exposure wavelength is 514.5 nm, with the incident angle of the reference light being $\theta_{ref}=45^\circ$ and the incident angle of the object light being 0° , $\theta_{ac}=21.4^\circ$ is obtained from the above expression. Then, the change in the reconstructed wavelength is only about 0.2 nm within the viewing angle range of $\pm 2^\circ$, which is required for a sign, whereby the change in color will not be recognized. Moreover, the color distribution within the reconstructed image can be suppressed to be extremely small. Since the reconstructed wavelength slightly shifts toward the long wavelength side, the producing optical system should preferably be set in view of such a shift.

30 Figure 27A illustrates an installation of the hologram when the installation angle is set to be close to θ_{ac} , and Figure 27B illustrates a normal installation of the hologram for comparison.

When the installation angle of a hologram 53 is set to be as close to θ_{ac} as possible, the optical path of illumination light 54 and that of reconstructed light 55 come closer to each other. Thus, in practice, it is preferable to install the hologram while setting the installation angle to be as close to θ_{ac} as possible and such that an observer 56 attempting to view the reconstructed image does not block the illumination light 54. It is more preferable to slightly move a linear light source for illumination, which is not shown, in the horizontal direction so that the illumination light 54 and the observer 56 do not overlap each other, as described in Embodiment 4.

The arrangement of the above-described embodiment as described above can be practiced with an optical display apparatus of any of the embodiments described in this specification.

(Embodiment 9)

It is possible to increase the size of the virtual display plane and that of the reconstructed image by increasing the size of the hologram. However, the exposure area which is normally realized by a hologram producing optical system is about $\phi 300$ mm to about $\phi 400$ mm, which presents the limit for the size of the reconstructed image. Although it is not impossible to realize an exposure area larger than this, there will then be problems as follows:

- (1) The production of optical components such as a lens, a mirror, or the like, is difficult and costly;
- (2) The light intensity decreases as the laser beam is extremely widened;
- (3) The exposure time increases because of (2)

above; and

(4) The exposure condition becomes unstable (increased probabilities for adverse effects such as air fluctuation, vibration, and laser stability) because of (3) above.

In order to avoid these difficult problems, with the optical display apparatus of the present invention, a large-size hologram is provided by providing small elementary holograms which can be produced under a more stable condition, and combining these elementary holograms together just like tiling.

Figure 28 illustrates an exemplary 1m×1m hologram. Herein, sixteen 25cm×25cm elementary holograms are arranged in a 4×4 matrix, thereby realizing the size of 1m×1m. Each elementary hologram is produced by using one of elementary masks which are obtained by dividing a pattern mask having a size of about 1m×1m, which is the object, into 4 equal parts. The problems as those described above do not occur in exposure for the size of 25 cm.

The arrangement of the above-described embodiment as described above can be practiced with an optical display apparatus of any of the embodiments described in this specification.

(Embodiment 10)

One feature of the optical display apparatus of the present invention that is not seen in conventional apparatuses is that the optical display apparatus whose basic arrangement has been shown in each embodiment may be used as one display unit, while a plurality of such units can be arranged on an arrangement plane so as to synthesize

and display reconstructed images from the respective units on the virtual display plane. For example, where the display units are arranged side by side as viewed from the observer, the display width can be widened in the horizontal direction by synthesizing the respective reconstructed images on the virtual display plane.

Figures 29A and 29B are a front view and a side view, respectively, of an exemplary optical display apparatus in which three display units 57 are arranged side by side.

A hologram reconstructed image 59 reconstructed by a fluorescent lamp 58 differs for the respective display units, and each display unit reconstructs and displays one of the characters "A", "B" and "C". When the respective display units are closely arranged together side by side, as illustrated in the figure, the characters are aligned together so that they can be recognized as one word.

It is preferable to arrange a shieldplate 60 between the units so that the fluorescent lamp for one unit does not reconstruct the fluorescent lamp for another unit.

(Embodiment 11)

Where the information to be displayed is a string of characters as in Figure 29A, even if there is a slight gap between the characters, the information is conveyed to the observer with no problem. However, where the information to be displayed is a pattern, any gap therein is undesirable, and in some cases the gap itself may be recognized as a piece of information, whereby the observer recognizes information which is different from the original information intended to be conveyed. In the case of the

reconstructed image 65 of the center display unit 64 with no gap therebetween.

As described above, according to the present invention, it is possible to combine reconstructed images together with no gap, thereby allowing large patterns to be displayed.

(Embodiment 12)

An arrangement which sufficiently exhibits the feature of the optical display apparatus of the present invention is one in which a plurality of display units are arranged along a depth direction of the reconstructed image as viewed from the observer, so that the reconstructed images from the respective holograms are synthesized on the virtual display plane.

Figure 31A is a side view illustrating a structure of an optical display apparatus according to Embodiment 12 of the present invention. In this embodiment, the optical display apparatus of the present invention is used as a traffic sign in a tunnel. Specifically, reference numeral 69 denotes an optical display apparatus of the present embodiment; 70 to 72 display units; 73 to 75 holograms; and 76 to 78 fluorescent lamps as linear light sources. The display units 70 to 72 are arranged side by side on a ceiling plane 80 of a tunnel 79.

An operation of the optical display apparatus 69 having such a structure will be described below.

First, an original picture pattern 81 of a traffic sign indicating a speed limit, as illustrated in Figure 31B,

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is divided into parts and recorded on the holograms 73, 74 and 75, respectively, by a method as that described in Embodiment 1 of the present invention. In particular, as illustrated in Figure 31C, an elementary pattern 82 for the lower approximately 1/3 portion obtained by dividing the original picture pattern 81, is recorded on the hologram 73, an elementary pattern 83 for the middle approximately 1/3 portion is recorded on the hologram 74, and an elementary pattern 84 for the upper approximately 1/3 portion is recorded on the hologram 75. Each hologram is produced by arranging a pattern mask for the elementary pattern and a hologram dry plate at a respectively different distance in an optical system for producing each hologram.

As illustrated in Figure 31A, a reconstructed image 85 of the hologram 73 formed by the fluorescent lamp 76 is arranged to be formed in the vicinity of a virtual display plane 86. Similarly, a reconstructed image 87 of the hologram 74 formed by the fluorescent lamp 77 and a reconstructed image 89 of the hologram 75 formed by the fluorescent lamp 78 are arranged to be formed in the vicinity of a virtual display plane 88 and a virtual display plane 90, respectively. Then, the reconstructed images 85, 87 and 89 as viewed from the front side thereof are synthesized into a single image, as illustrated in Figure 31D. Thus, the reconstructed image is viewed from a car running through a tunnel 79 as if it were a traffic sign indicating a speed limit hung from a ceiling plane 80 of the tunnel 79. However, this is only a display on the virtual display plane, and there is no object actually existing on the display plane. Therefore, there is no chance for a car collision.

An advantage of this structure is that it is possible to reduce the height of the display unit by a rate of approximately $1/N$, where N denotes the number of display units provided. Thus, the cross section for which a tunnel is to be dug through can be reduced by employing an optical display apparatus having such an extremely flat structure. This provides a substantial reduction in the construction cost.

(Embodiment 13)

Figure 32 is a perspective view of an optical display apparatus according to the present embodiment. This is an example for displaying the position of an emergency phone in a tunnel. Reference numeral 91 denotes a fluorescent lamp, 92 a hologram unit, and 93 an emergency phone.

The hologram unit 92 has a structure as illustrated in Figure 33. Specifically, reference numeral 94 denotes a first hologram, 95 a second hologram, and 96 a display board. The first hologram 94 and the second hologram 95 are arranged to form a reconstructed image on the side of a first plane 97 of the hologram unit 92 and on the side of a second plane 98 of the hologram unit 92, respectively. Information identical to display information to be reconstructed by the first hologram 94 is written on a first plane 99 of the display board 96 to which the first hologram 94 is attached. Similarly, information identical to display information to be reconstructed by the second hologram 95 is written on a second plane 100 of the display board 96 to which the second hologram 95 is attached.

The hologram unit 92 having such a structure is arranged under the fluorescent lamp 91 as a linear light

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source, as illustrated in Figure 32. Referring to the side view of Figure 34 in order to describe an operation of the hologram unit 92, a reconstructed image 103 of the first hologram 94 is formed by illumination light 102 emitted from a region 101 of the fluorescent lamp 91. In this example, the characters "Emergency Phone" are displayed. On the other hand, a reconstructed image 106 of the second hologram 95 is formed by illumination light 105 emitted from a region 104 of the fluorescent lamp 91, thereby similarly displaying the characters "Emergency Phone". Therefore, it is possible to clearly indicate the position of the emergency phone 93 to people on both sides of the optical display apparatus. In this example, the character information "Emergency Phone" is written on both sides of the display board 96, whereby a display on the opposite side can be recognized through a transparent hologram plane. Therefore, even in an emergency where the fluorescent lamp 91 does not light up, for example, the position of the emergency phone 93 can be recognized by using a flash light.

While a case where identical information is displayed has been described above, it is understood that it is possible to display different information on the opposite sides by recording different information on the respective holograms.

(Embodiment 14)

Figure 35 is a perspective view of an optical display apparatus according to the present embodiment. Reference numeral 107 denotes a fluorescent lamp, 108 a first hologram unit, and 109 a second hologram unit.

Each of the hologram units 108 and 109 has a structure as illustrated in Figure 36. In particular, reference numeral 110 denotes a first hologram, 111 a first display board, 112 a second hologram, and 113 a second display board. The first and second hologram units 108 and 109 are arranged near the respective ends of the fluorescent lamp 107 as a linear light source, as illustrated in Figure 35.

An operation of the optical display apparatus according to the present embodiment will be described with reference to Figure 37.

A reconstructed image 115 of the first hologram 110 is formed by illumination light 114 emitted from the fluorescent lamp 107. On the other hand, a reconstructed image 117 of the second hologram 112 is formed by illumination light 116 emitted from the fluorescent lamp 107. Therefore, it is possible to display identical or different information to people on both sides of the optical display apparatus.

Information identical to the reconstructed image 115 of the first hologram 110 and information identical to reconstructed image 117 of the second hologram 112 are recorded on the first display board 111 and on the second display board 113, respectively, and can be recognized from the opposite side through transparent hologram plane. Therefore, even in an emergency where the fluorescent lamp 107 does not light up, for example, the information can be recognized by using a flash light.

5 The structure of an optical display apparatus for simultaneously reconstructing such a plurality of holograms is not limited to this embodiment, but various other structures are possible by effectively utilizing light which is omnidirectionally emitted from the linear light source as illumination light.

10 While the reference light 16 is directed to be incident upon the incident plane 15 in a hologram producing process in Embodiment 1, the present invention is not limited to this. It may also be effective to intentionally not employ the arrangement. For example, when a hologram is formed by directing the object light to be incident upon the incident plane while directing the reference light to be incident upon a plane different from the incident plane, the reconstructed image can be viewed from the front side of the hologram for illumination light coming from the left-hand side in the arrangement of the fluorescent lamp and the hologram illustrated in Figure 38. Moreover, since 20 the direction of the reflected light of the illumination light is different from the direction in which the reconstructed image is obtained, an easy-to-view display is realized.

25 (Embodiment 16)

The method for producing a hologram of the present invention is not limited to that described in Embodiment 1. For example, it is possible to first reconstruct an image which has been recorded as a transmission-type hologram, and then to record it as a reflection-type hologram. 30

Figures 39A and 39B are a side view and a plan view, respectively, of an optical system for producing a

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transmission-type hologram according to the present embodiment.

As illustrated in Figure 39A, laser light 126 incident upon a ground glass 125 so as to be diffused light 127 and then incident upon a slit 128. The slit 128 has a narrow width as viewed from a side thereof, and transmits only a portion of the diffused light 127. Therefore, light having passed through the slit 128 appears as spread light coming from a single point as viewed from the side. This light reads the information of a pattern mask 129, and irradiates a hologram dry plate 130 as object light 131. This can be considered as projection of the pattern mask 129 onto the hologram dry plate 130. The object light 131 including the information of the object forms interference fringes with reference light 132 incident upon the same side of the hologram dry plate 130, and the interference fringes are recorded on the hologram dry plate 130.

At this time, the "shadow" of the pattern mask 129 projected onto the hologram dry plate 130 has been enlarged. In view of the rate of projection magnification, the pattern mask 129 is produced while being shrunk in one direction. Although the rate of magnification varies depending upon the setting of the optical system, it normally is about 1.2 to about 2.

As illustrated in the plan view of Figure 39B, the slit 128 has a large width as viewed from the above, and transmits diffused light 127 coming from the ground glass 125 over a wide range. In Figure 39B, diffused light having passed through the central portion of the slit 128

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thereby providing a master hologram 144.

In Figure 42, a reconstructed image of the object 139 is obtained by directing illumination light 145, which is conjugate light of the reference light 143, to be incident upon the master hologram 144. Herein, a slit 146 is arranged in the vicinity of the master hologram 144 so as to use light coming through the slit 146 as object light 147, so that interference fringes are formed between the object light 147 and reference light 149 incident upon the reverse side of a hologram dry plate 148. The interference fringes are recorded on the hologram dry plate 148 as a reflection-type hologram. Reference numeral 150 denotes a reconstructed image of the object 139.

By employing such a method, it is possible to obtain an unblurred reconstructed image for a three-dimensional object or an object spaced apart from the hologram plane.

(Embodiment 18)

Figure 43 illustrates an optical system for producing a hologram according to Embodiment 18. This is also a process of producing a transmission-type hologram once and then forming a reflection-type hologram while using it as a master hologram.

The optical system of Figure 43 differs from that of Figure 42 in that a negative cylindrical lens 151 and an opening 152 are provided in place of the slit 146. By the action of the cylindrical lens 151, it is possible to match the position in the vertical direction in the figure where reconstructed light 153 forms an image with a hologram dry plate 154, whereby it is possible to obtain a sharp

reconstructed image for a three-dimensional object or an object spaced apart from the hologram plane. Reference numeral 155 is a reconstructed image of object 139.

5 In Figure 43, the cylindrical lens 151 having a negative power is used, assuming a case where the reconstructed image 155 is formed between the master hologram and the hologram dry plate. However, when the reconstructed image 155 is formed on the left side of the hologram dry plate 154 in Figure 43, a cylindrical lens having a positive power is used.

(Embodiment 19)

15 Figure 44 is a side view illustrating a structure of an optical display apparatus according to Embodiment 19 of the present invention. In this embodiment, the optical display apparatus of the present invention is used as a traffic sign in a tunnel.

20 In Figure 44, reference numeral 201 denotes an optical display apparatus of the present embodiment, 202 a hologram screen, 203 a cylindrical lens, and 204 an LED display apparatus. The optical display apparatus 201 is arranged on a ceiling plane 206 of a tunnel 205. As shown in the figure, the width direction (perpendicular to the figure), the longitudinal direction and the vertical direction of the tunnel 205 are denoted as the x, y and z directions, respectively.

30 An image displayed on the LED display apparatus 204 is projected by the cylindrical lens 203 onto the hologram screen 202. The image diffracted and reflected by the hologram screen 202 is reconstructed and imaged on a virtual

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the hologram screen 202. As a result, when a normal projection screen is placed at the position of the hologram screen 202, an image will be viewed where only the line or outline extending along the x direction is clear while the line or outline extending along the z direction is blurred, as illustrated in Figure 45. Figure 45 is a schematic illustration showing how a circular image and a square image imaged by the cylindrical lens 203 will appear on a normal projection screen being placed at the position of the hologram screen 202.

Next, a function of the hologram screen 202 will be described.

Figures 46A and 46B are a plan view and a side view, respectively, illustrating a structure with only the hologram screen 202 and the LED display apparatus 204 of the optical display apparatus 201. In the absence of the cylindrical lens 203, the hologram screen 202 has a function of imaging the light from point A on the LED display apparatus 204 to point B on the virtual display plane 208.

The hologram screen 202 having such a function can be produced by, for example, an exposure optical system illustrated in Figure 47. In particular, a laser beam 211 focused by a lens 210 becomes diffused light after passing through a pin hole 212 placed at the position of point A, and is incident upon a hologram dry plate 213, which will later be the hologram screen 202, from the right side of the figure. On the other hand, a laser beam 214 converging to point B is incident upon the hologram dry plate 213 from the left side of the figure, i.e., from the opposite side to the laser beam 211. The hologram screen 202 having such a

point A once spreads out in the z direction and passes through the cylindrical lens 203 so that only the z component thereof converges to point C with a certain convergence angle. Therefore, after being diffracted and reflected by the hologram screen 202, the light is projected onto the virtual display plane 208 as divergent light having a small divergence angle along the z direction.

Strictly speaking, the respective light beams contained in the divergent light have slightly different wavelength components. That is, the emission distribution of the display apparatus has a width of several ten nm, and the light is split by the hologram screen 202 while being diffracted and reflected at different angles for the respective wavelengths.

It has been described above how the image displayed on the LED display apparatus 204 travels to be projected and imaged on the virtual display plane 208 separately for the x component and the z component. Next, how the image is consequently viewed by the eyes of an observer 215 will be described.

Figures 49A and 49B are a plan view and a side view, respectively, illustrating only part of the light beams illustrated in Figures 48A and 48B after the hologram screen 202, and illustrating the path of the light beams to the pupils of the observer 215 who is viewing the image at a position spaced apart from the virtual display plane 208.

As illustrated in Figure 49A, similar light beams as those obtained when light comes from the single point B on the virtual display plane 208 are incident upon the left

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empirically possible to determine approximately how far the long straight line is located in the horizontal direction.

For the vertical direction, on the other hand, such
5 a binocular parallax does not occur because the human eyes
are located at the same height. As a result, it is relatively
difficult to perceive the three-dimensional feeling or the
depth feeling. For example, assuming, for simplicity, a
10 case where a laterally extending long straight line is viewed
by both eyes, both the right eye and the left eye can recognize
it as a laterally extending long straight line. However,
no parallax occurs because the image is projected onto the
same position for both eyes. Therefore, it is not possible
15 to definitely determine how far the long straight line is
located in the vertical direction. For example, this
corresponds to a case where a person attempting to jump up
to a high horizontal bar might hesitate to jump for a moment
because they cannot grasp the distance to the horizontal
20 bar which appears to extend in the horizontal direction in
the background sky.

Importantly, the binocular parallax in the
horizontal direction is the most dominating factor for the
three-dimensional feeling or the depth feeling. Based on
25 this, how the x and z components of the above-described
optical display apparatus of the present invention appear
will be discussed.

What is shown in Figure 49A is the fact that the sharp
30 line or outline of the x component of the image is viewed
by each of the left and right eyes of the observer 215 on
the virtual display plane 208. Using the above figure of
speech, this corresponds to how the vertically extending

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long straight line appears. Since the binocular parallax occurs for the respective left and right eyes of the observer 215, it is recognized that the image is located just on the virtual display plane 208.

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On the other hand, what is shown in Figure 49B is the fact that the sharp line or outline of the z component of the image is viewed by each of the left and right eyes of the observer 215 on the hologram screen 202. Using the above figure of speech, this corresponds to how the laterally extending long straight line appears. Since no binocular parallax occurs for the respective left and right eyes of the observer 215, the position of the image cannot clearly be determined.

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Therefore, the sharp line or outline of the x component is the primary factor for the binocular parallax, and is the dominating factor for the recognition of a position. As a result, the image appears to the observer's eyes as if it were floating at the position of the virtual display plane 208.

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Although it has been omitted in the above description, the relative installation angle among the hologram screen 202, the cylindrical lens 203 and the LED display apparatus 204 is intentionally inclined. This is done so that a matrix array of pixels, which are normally formed on the LED display apparatus 204 equidistantly in the vertical direction and in the lateral direction, are clearly imaged on the hologram screen 202 without being distorted. This is a technique called "front rising" which is employed when photographing architecture. In particular, when architecture such as a tall building is photographed by an

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ordinary camera while looking up, it is photographed while the shape of the building, which is originally rectangular, becomes a trapezoid as illustrated in Figure 50. The front rising method is used for correcting such a distortion in the shape and taking a photograph with the entire object being focused.

A procedure of the front rising method is illustrated in Figures 51A to 51D. Herein, reference numeral 216 denotes a film surface, and 217 a shooting lens.

In particular, the camera is first directed from the normal position (Figure 51A) toward the object (Figure 51B), and then only the film surface 216 is inclined in the direction parallel to the object (Figure 51C). Then, the above-described distortion of the object is corrected. Next, the shooting lens 217 is inclined toward the direction parallel to the object (Figure 51D). Then, the entire object becomes focused. Incidentally, the nomenclature "front rising" comes from the fact that the shooting lens 217 is raised with respect to the film surface 216 as a result of the above-described procedure.

Figure 52 is a diagram illustrating only the hologram screen 202, the cylindrical lens 203 and the LED display apparatus 204 of the optical display apparatus 201 of the present embodiment, with the elements being rotated counterclockwise. It can be seen that, considering the LED display apparatus 204 as an object, the cylindrical lens 203 as a shooting lens, and the hologram screen 202 as a film surface, the optical display apparatus 201 of the present embodiment has the same structure as that of the above-described front rising technique.

What is described above is an arrangement of the optical display apparatus 201 which is employed assuming that the LED display apparatus 204 has a matrix arrangement of pixels which are provided equidistantly in the vertical direction and in the lateral direction. However, the arrangement may vary in the case where it is possible to use a display apparatus having a pixel arrangement for correcting a trapezoidal distortion as illustrated in Figure 50.

Figure 53 is an arrangement employed when using a display apparatus 218 which originally has a pixel arrangement of a vertically inverted trapezoid for correcting the trapezoidal distortion.

The respective planes (indicated as straight lines in the figure) on which the hologram screen 202, the cylindrical lens 203 and the display apparatus 218 are respectively arranged so that the extension lines thereof meet together at a single point. This is called a Scheimpflug condition and is well known in the art of photography. When this condition is satisfied, the entire image displayed on the display apparatus 218 is clearly projected onto the hologram screen 202.

According to the present invention, the color slightly varies among the light beams in the z direction, but the change in color among those received by a pupil is small, and thus they appear to have a single color. In the above description of the method for producing the hologram screen 202, only a method using a single color laser is described. However, it is possible to display a color image by performing multiple exposure with red, blue and green

lasers using a similar method.

Moreover, while the cylindrical lens 203 is used in the present embodiment, the present invention is not limited thereto. Any other structure may alternatively be used as long as it clearly projects and images the z component of an image on the hologram screen 202 as described above. For example, an anamorphic optical system having different focal distances for the vertical and lateral directions or a combination of a normal projection lens and a cylindrical lens may be used. Particularly, when using a lens or a mirror in which the focal distance in the x direction can be varied, it is possible to easily change the position along the depth direction where the image is viewed. For example, when a varifocal lens 301 having a power only in the x direction is arranged as illustrated in Figures 54A and 54B, the position of the virtual display plane 208 where the image is formed is moved back and forth without changing the position of the LED display apparatus 204. It is also possible to employ an arrangement where the optical path is folded by using a varifocal mirror in place of the varifocal lens 301.

While an LED display apparatus is used as an image display apparatus in the present embodiment, the present invention is not limited thereto but may employ any image display apparatus capable of displaying a bright image. For example, it is possible to use an image display apparatus comprising: a display device selected from an LED, a CRT, a polymer dispersed type liquid crystal panel and an organic EL panel; and a polarization switching device. As the polarization switching device, an arrangement including a ferroelectric liquid crystal panel may be used.

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As described above, with the optical display apparatus of the present invention, an image displayed on the LED display apparatus 204 is reconstructed and imaged on the virtual display plane 208. However, this is only a display on the virtual display plane 208, and there is no object actually existing on the virtual display plane 208. Therefore, there is no chance for a car collision. Moreover, since the height of the overall apparatus can be set to be low, it is possible to provide a display apparatus with which a small space can be efficiently utilized.

Moreover, while the optical display apparatus of the present invention has been primarily described with respect to an application for a traffic sign in a tunnel, the present invention is not limited thereto. Another optical display apparatus in a form similar to that described above in the present embodiment can easily be used as a projection type display. Utilizing the characteristic that an image appears as if it were floating apart from the screen surface toward the viewer, various applications may be possible in the field of games, amusement, etc.

In Figure 47, the laser beam 214 converging to point B is directed to be incident upon the hologram dry plate 213 from the left side of the figure when producing the hologram screen 202. However, it may be replaced with a laser beam 219 which is divergent light coming from point E which is located on the left side of the hologram dry plate 213, as illustrated in Figure 55. A hologram screen 220 produced in this manner is arranged as illustrated in Figure 56. Since the elements except for the hologram screen 220 are not changed at all, the elements are arranged as described above so that an image displayed on

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the LED display apparatus 204 is projected and imaged by the cylindrical lens 203, whereby the line or outline contained in the image which extends along the x direction, for example, is most clear on the hologram screen 220.

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On the other hand, the x component of the image is not effected by the cylindrical lens 203. Therefore, it may be considered that the image displayed on the LED display apparatus 204 is projected onto the hologram screen 220 as it is. Therefore, by the function of the hologram screen 220, only the x component (i.e., the line or outline extending along the z direction) is sharply imaged on a virtual display plane 221, which is newly formed at the position where a point image E as a false image on the left side of the hologram screen 220 was located. Since a clear image of the x component is viewed by the observer on the virtual display plane 221 beyond the hologram screen 220, an image is recognized as if it were floating at this position as in the above description.

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While such an optical display apparatus can be used as a traffic sign as in the above description, a more suitable field of application is a head-up display. In the most commonly known application, it is arranged on the dashboard of a car so as to display traffic information, speed information, navigation information, etc., which are required for driving the car, beyond the windshield and above the bonnet. An exemplary arrangement for use in such an application is illustrated in Figure 57. In this case, other than an LED display apparatus, a CRT, a liquid crystal display apparatus, a fluorescent display tube, an organic EL, and the like, may be used as the display apparatus 204. Moreover, the hologram screen 220 is produced through an

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dimensional image. There has been a research and development for solving the problem.

By applying the above-described three-dimensional image display principle to the display apparatus of the present invention, it is possible to provide a new three-dimensional display apparatus which solves such problems. The arrangement is schematically shown in Figure 58. Specifically, reference numeral 420 denotes a hologram screen, 402 a spatial light modulation device, and 403 a projection optical system. A three-dimensional image 406 is observed by an observer 415 wearing polarization glasses 404.

Herein, the spatial light modulation device 402 may be any image display apparatus capable of switching the polarization direction of the displayed image, and may be those capable of switching the direction of linearly-polarized light, those capable of switching the rotary direction of circularly-polarized light, or the like. As the spatial light modulation device 402, those operating at 120 Hz or more are commonly available, with which a three-dimensional image can be displayed based on the binocular parallax by switching images from one to another at a speed such that the switching cannot be recognized by human eyes. The spatial light modulation device 402 may alternatively be provided by using such a device as the polarization switching device in combination with a non-polarization type display device, e.g., a CRT, an organic EL, a polymer dispersed type liquid crystal panel, etc.

Moreover, as the simplest arrangement for the projection optical system 403, a cylindrical lens may be used as already described above. However, the projection optical system 403 is not limited thereto, but may be any system which clearly projects and images the z component of the image on the hologram screen 420. For example, an anamorphic optical system having different focal distances for the vertical and lateral directions or a combination of a normal projection lens and a cylindrical lens may be used. As described above, when using a lens or a mirror in which the focal distance in the x direction can be varied, it is possible to easily change the position along the depth direction where the image is viewed. For example, when a varifocal lens having a power only in the x direction is arranged as illustrated in Figures 54A and 54B, the position of the virtual display plane where the image is formed is moved back and forth without changing the position of the LED display apparatus. It is also possible to employ an arrangement where the optical path is folded by using a varifocal mirror in place of the varifocal lens.

The respective orientations of the polarizing plates of the polarization glasses 404 are arranged to be orthogonal to each other, so that images, which are switched from one to another by the above-described spatial light modulation device 402, can be independently recognized by the right eye and the left eye by wearing the polarization glasses 404.

A feature of the three-dimensional display apparatus of the present invention is that the screen surface and the position where the image is observed can be separated from each other, while the distance therebetween can be

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varied. This is what makes it possible to solve the above-described problems such as the tired feeling. In particular, since the image is not fixed on the screen surface, the focus of the eye is adjusted to the actual image, but not to the screen. Moreover, since the position of the image can be changed, it is possible to adjust the focus of the eye and the angle of convergence to where the actual image is being viewed, thereby allowing for a natural three-dimensional display.

(Embodiment 21)

As described above, one feature of the optical display apparatus of the present invention that is not seen in conventional apparatuses is that the optical display apparatus whose basic arrangement has been shown in each embodiment may be used as one display unit, while a plurality of such units can be arranged on an arrangement plane so as to synthesize and display reconstructed images from the respective units on the virtual display plane.

Figure 59A and 59B are a side view and a front view, respectively, of an exemplary optical display apparatus in which three display units 233 are arranged side by side.

An image 225 formed on a virtual display plane 224 differs for the respective display units, and in the illustrated example, each display unit reconstructs and displays one of the characters "A", "B" and "C". When the respective display units are closely arranged together side by side, as illustrated in the figure, the characters are aligned together so that they can be recognized as one word.

Alternatively, as illustrated in Figure 60, a single large pattern may be displayed while being divided into three patterns 270, 271 and 272, which are synthesized together on the virtual display plane.

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Thus, in the case where the display units are arranged side by side as viewed from the observer, the display width can be widened in the horizontal direction by synthesizing the respective reconstructed images on the virtual display plane.

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Moreover, an arrangement which sufficiently exhibits the feature of the optical display apparatus of the present invention is one in which a plurality of display units are arranged along a depth direction of the image as viewed from the observer, so that the images from the respective display units are synthesized on the virtual display plane.

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Figure 61 is a side view illustrating a structure of an optical display apparatus 226 in which a plurality of display units are arranged in a depth direction of an image. In this embodiment, the optical display apparatus 226 of the present invention is used as a traffic sign in a tunnel. Specifically, in Figure 61, reference numeral 226 denotes an optical display apparatus of the present embodiment, and 227 to 229 display units, and the display units 227 to 229 are aligned with one another on a ceiling plane 231 of a tunnel 230.

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A hologram screen of each of the display units 227 to 229 is produced by the producing optical system illustrated in Figure 62A to 62C. Each of these optical

systems is basically the same as that illustrated in Figure 47. However, they differ from one another on the point at which an incident laser beam as convergent light is focused.

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Figure 62A illustrates an optical system for producing a hologram screen used in the display unit 227, and a laser beam 232 is incident so as to converge to point F. Figure 62B illustrates an optical system for producing a hologram screen used in the display unit 228, and a laser beam 233 is incident so as to converge to point G. Figure 62C illustrates an optical system for producing a hologram screen used in the display unit 229, and a laser beam 234 is incident so as to converge to point H.

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As illustrated in Figure 61, an image 235 of the display unit 227 is formed in the vicinity of a virtual display plane 236. Similarly, an image 237 of the display unit 228 and an image 239 of the display unit 229 are formed in the vicinity of a virtual display plane 238 and a virtual display plane 240, respectively.

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Elementary patterns 242, 243 and 244, as illustrated in Figure 63B, which are obtained by dividing an original picture pattern 241 of a traffic sign indicating a speed limit, as illustrated in Figure 63A, are displayed on the display units 227, 228 and 229, respectively. In particular, an elementary pattern 242 for the lower approximately 1/3 portion obtained by dividing the original picture pattern 241 is displayed as the image 235 on the display unit 227. Similarly, an elementary pattern 243 for the middle approximately 1/3 portion is displayed as the image 237 on the display unit 228, and an elementary pat-

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tern 244 for the upper approximately 1/3 portion is displayed as the image 239 on the display unit 229.

Then, the reconstructed image 235, 237 and 239 as viewed from the front side thereof are synthesized into a single image, as illustrated in Figure 63C, which is viewed from a car running through the tunnel 230 as if it were a traffic sign indicating a speed limit hung from the ceiling plane 231 of the tunnel 230. However, this is only a display on the virtual display plane, and there is no object actually existing on the display plane. Therefore, there is no chance for a car collision.

An advantage of this structure is that it is possible to reduce the height of the display unit by a rate of approximately $1/N$, where N denotes the number of display units provided. Thus, the cross section for which a tunnel is to be dug through can be reduced by employing an optical display apparatus having such an extremely flat structure. This provides a substantial reduction in the construction cost.

As described above, the optical display apparatus using the hologram of the present invention has an extremely high industrial value because it allows, for the first time, one to use a light source such as a fluorescent lamp which is inexpensive and has a long life.

However, the light source for utilizing the feature of the optical display apparatus of the present invention is not limited to a fluorescent lamp, but may be any elongated linear light source. In addition to the combination of a lamp with a vertically elongated opening, and the straight

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tube fluorescent lamp, as described above, a one-dimensional array of small electric bulbs, a one-dimensional array of semiconductor lasers or LEDs, an organic EL in which the light emitting section is linearly shaped, a light source including a linear optical output section which is provided by guiding light from a light source by using light guiding means such as an optical fiber, and the like, can easily be used as the linear light source. Furthermore, various alternatives can be used. For example, it is possible to provide a pseudo-linear light source by combining a point light source with a cylindrical mirror or with a polygon mirror. It is also preferable to use a decentered mirror to reduce the size. Alternatively, it is possible to form a linear light source by using light beams which are linearly focused by a mirror or a lens. With this structure, it is possible to provide a virtual linear light source having a high brightness at a position near the hologram. Alternatively, it is possible to allow a two-dimensional display apparatus such as a CRT to function as a linear light source by displaying a vertical elongated bright line thereon. If the position where the bright line is displayed is successively moved, the reconstruction position also moves in response thereto, whereby it is possible to produce an effect that the reconstructed image is viewed as moving. Other than this, similar effects can be provided by using a movable linear light source.

Regarding the emission characteristics of the light source, the light source to be used may have a continuous emission distribution or independent emission peaks corresponding to the three primary colors. Alternatively, a linear light source may be provided by combining independent light sources corresponding to the three primary

colors. In this way, it is possible to turn on/off the light sources of the respective colors, thereby allowing for an extremely effective display where a reconstructed image of a particular color is displayed or not displayed.

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In Figure 8, when the hologram 2 is reversed by 180° about an axis orthogonal to the figure plane, the virtual display plane on which the reconstructed image is formed is moved to the other side of the hologram 2, i.e., to the other side of the ceiling plane 7 in Figure 8, whereby the reconstructed image is formed on the other side of the hologram 2. The optical display apparatus of the present invention can produce such a display of a reconstructed image. However, in such a case, the obtained reconstructed image is reversed. Therefore, when displaying a reconstructed image with such an arrangement, it is necessary to previously set the pattern mask so as to face toward the hologram dry plate when producing the hologram 2.

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When the reference light is formed by directing a plurality of beams to overlap with one another in the direction orthogonal to the longitudinal direction of the slit, it is possible to widen the viewing range without using a linear light source during the reconstruction. In such a case, the illumination light source may be a point light source. However, positions where the reconstructed image is observed are inherently discrete. Therefore, as the view point is moved in the vertical direction, a position where the reconstructed image can be viewed and a position where it is difficult to view the reconstructed image will alternately occur. This condition varies depending upon how much the plurality of beams used when producing the hologram overlap with one another. In the case where the

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plurality of beams are arranged to be adjacent to one another, the reconstructed image is observed without interruption even when the view point is moved. This reference light arrangement is effective not only when the object light is formed by combining a slit and diffused light, but also when a cylindrical lens is further combined therewith, when a reconstructed image of a transmission-type hologram is used as object light, or when the object light is provided by diffused light diffusing in one direction.

Alternatively, the viewing range can be widened by exposing the hologram while arranging a one-dimensional diffuser such as a lenticular lens sheet to be adjacent to the hologram dry plate, without using a linear light source during the reconstruction. In such a case, the illumination light source may be a point light source. However, positions where the reconstructed image is observed are inherently discrete. Therefore, as the view point is moved in the vertical direction, a position where the reconstructed image can be viewed and a position where it is difficult to view the reconstructed image will alternately occur. This condition varies depending upon the specification of the lenticular lens sheet. By selecting a lenticular lens sheet having a fine pitch, the reconstructed image is observed without interruption even when the view point is moved.

The reconstruction display plane is not limited to a single plane, but may be formed by a plurality of planes or a curved surface. Moreover, as already described in some of the embodiments above, a three-dimensional object may be used as the object. However, when a three-dimensional object is used as the object with the hologram producing optical system illustrated in Figures 10, 11A and 11B, it

is necessary to rearrange the optical system so that the reflected light from the object, which is generated by irradiating the three-dimensional object with laser light, passes through a slit placed between the object and the
5 hologram dry plate. Also in such a case, while the light having passed through a slit becomes the object light, the laser light and the object light will not be aligned with the optical axis.

10 A duplicate of the hologram 2 can easily be produced. For example, the information recorded on the hologram 2 can be transferred and duplicated onto a hologram dry plate by closely attaching together the hologram 2 and an unexposed
15 hologram dry plate, preferably via a refractive index matching solution, and by directing laser light to be incident thereupon from the hologram dry plate side at an appropriate angle.

20 In the above-described embodiments, an optical traffic sign and a traffic information display board have been mainly described as applications of the present invention. However, the present invention is not at all limited to such applications, but may also display general character information, advertising bill, etc. Similarly,
25 the location where the hologram is installed is not limited to the inside of a tunnel, but a significant effect is also provided when it is installed in a building, an elevator, an underground town, a train station, or the like. Moreover, it is also possible to employ an arrangement such that
30 non-diffracted light which is not diffracted by the hologram is used for ambient illumination.

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Furthermore, the position where the hologram is installed is not limited to the ceiling, but it is also effective to install the hologram on a wall surface, a floor, or the like. For example, by installing a hologram on a floor surface of a hall so that it is reconstructed by a fluorescent lamp for illumination which has been provided on the ceiling so as to display as a reconstructed image an indication indicating an arrow, a position, etc., the hologram functions as a guide sign. Particularly, it can easily be viewed when it is arranged so that the reconstructed image is displayed while floating apart from the floor surface by several ten cm. Alternatively, such a display may be used as means to stop a passer-by since it attracts people's attention.

(Embodiment 22)

With the optical display apparatus using a hologram based on the principle of the present invention, it is possible to present a space to the observer by displaying an indication indicating an arrow or a location as a reconstructed image. As an exemplary application of this feature, a system for visualizing and presenting to a user a position through which a non-contact type card is to be passed will be described in the present embodiment.

In the case of a railroad station, for example, automatic ticket gate systems currently installed are mainly those of the type which magnetically reads information recorded on a pass. However, it has been proposed to replace them in the future with those of a type which reads information of a pass carried by a user by means of an electric wave, or the like, in a non-contact manner. This aims to replace the existing ticketing system, where the pass is

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supposed to be inserted into a machine, to improve the ticketing efficiency and realize a smoother flow of people by allowing a user to pass through the gate while holding a non-contact type card pass in its hand.

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A point about which to be concerned is whether the user can effectively pass the pass through a predetermined communication area (e.g., an area where a signal is read by a radio wave) which is prescribed in a space spaced apart from a card reader. If the user cannot accomplish this well and thus has to repeat the reading operation, it will rather stagnate the flow of people through the ticket gate.

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The problem of effectively passing a card through the communication area is inherent to the non-contact type card system because, with a conventional reader, the user is only required to insert the card into the slot, and the positioning of the card for the reading operation is automatically done by the machine. Therefore, the user bears no burden for the card to be properly read. With the non-contact type card system, on the other hand, the communication area is spatially spread out, and it is an essential condition to bring the card into the optimal communication area and to keep the card presented within the communication area for a period of time which is required for reading the information thereon. The user is responsible for all of such tasks.

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In order to reliably read the card without imposing a burden on the user under such circumstances, it is considered as an effective measure to visualize a position (area) through which the non-contact type card should be passed. With the optical display apparatus of the present

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invention, it is possible to display an indication such as an arrow in the form of a clear color image obtained by reconstructing a hologram in a communication area which is spaced apart from the card reader, whereby it is possible to reliably present a position where the card should be put for the user passing by the position.

Moreover, users passing through a ticket gate are generally in a hurry. Therefore, a display where the communication area is seen only when the user is passing by the area does not provide the intended function. This is because the action of moving the card to the optimal position after the display is seen imposes a burden on the user. Thus, in order to reliably inform the user of the position of the communication area, the display should be such that the user can generally grasp the position of the communication area as the user approaches the ticket machine. The optical display apparatus of the present invention effectively functions for this purpose.

For example, as described above in connection with Embodiment 3, with the optical display apparatus of the present invention, the display viewing range can be widened back and forth by adjusting the arrangement of the light source. By using this function, it is possible to create a situation where the user sees something when the user is still away from the ticket gate. Therefore, the user can prepare to present the card under the guidance of what is seen. As the user approaches the ticket gate, the display starts to appear clearer, whereby the user can certainly see where to put the pass. When the user actually passes the ticket gate, the user can pass by while holding the card at an appropriate height and position, thereby allowing for

a reliable information reading operation.

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5 The above-described "situation where the user sees something" may be provided by any display which attracts a person's attention, e.g., as the user walks toward the presented position, the position appears blinking or appears to change in color. The feature of the present invention, i.e., a hologram produced by a plurality of reference light beams alternately appears and disappears as the viewing position changes, can be effectively used for this purpose. 10 Alternatively, this can be realized by providing the optical display apparatus while avoiding an arrangement in which the change in color is small.

15 Regarding the viewing range, it is preferable that the range is set to be wide in the front side while the range is such that the presented position can still be seen when the user looks back after passing by the position. This can also be realized by defining the display viewing range by 20 adjusting the arrangement of the light source as described above in connection with Embodiment 3.

25 Since the user's height differs between individuals, the position preferably appears bright even when the viewing height changes. This can be realized by increasing the degree of diffusion of the diffuser used when producing the hologram while elongating the slit, or by increasing the width of the one-dimensional diffuser and the degree of diffusion thereof.

30 Incidentally, Japanese Laid-Open Publication No. 9-6935 relating to a wireless card processing apparatus describes that a three-dimensional stereoscopic image is

collision with the display apparatus.

Moreover, according to the present invention, it is possible to use a fluorescent lamp as a reconstruction light source, whereby the reconstructed light source is available
5 anytime and anywhere. Thus, by producing a hologram on a light-weight flexible substrate, it is possible to realize a display apparatus which can easily be carried around.

Furthermore, by applying this principle, a novel display, such as a head-up display or a three-dimensional display apparatus, is realized in which an image is observed at a position spaced apart from the screen surface.
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For example, when the optical display apparatus of the present invention is used in a non-contact type card system, a spatially spread communication area can be clearly presented to the user, whereby it is possible to more reliably and effectively provide the function inherent to
15 the non-contact type card system.
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